Improving the neutrino detection at Pierre Auger Observatory

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THE SEARCH FOR NEUTRINOS

Detection of very high energy neutrinos can complement other observations giving us more information over an event – multi-messenger approach.

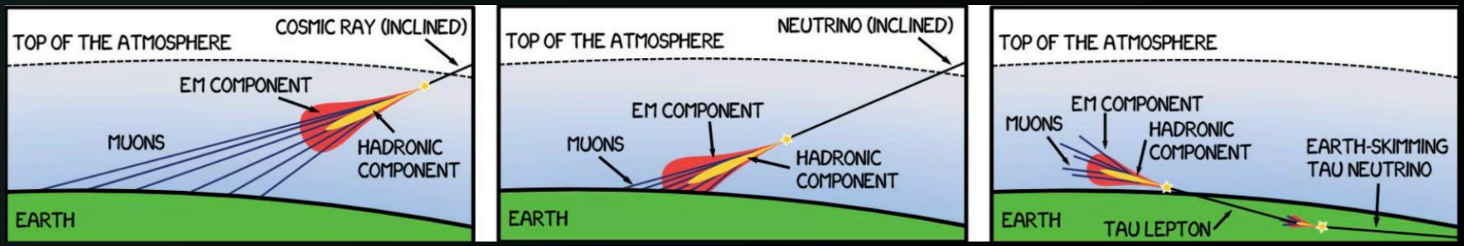
- Neutrinos have no charge, almost massless
- They can easily escape their sources
- Not deflected or absorbed during propagation towards Earth
- Can pinpoint direction of source

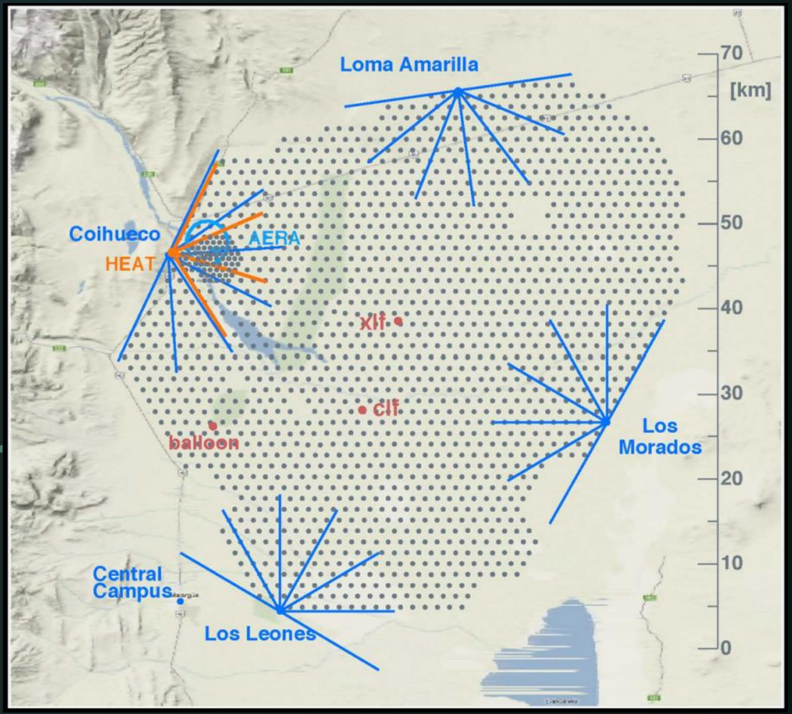
EXTENSIVE AIR SHOWERS

- Highly energetic particles create showers upon entering the atmosphere
- Shower has 3 components:
  - Electromagnetic
  - Hadronic
  - Muonic
- Muons are produced by the hadronic component

PIERRE AUGER OBSERVATORY

- Located in Argentina
- Built to detect UHECR





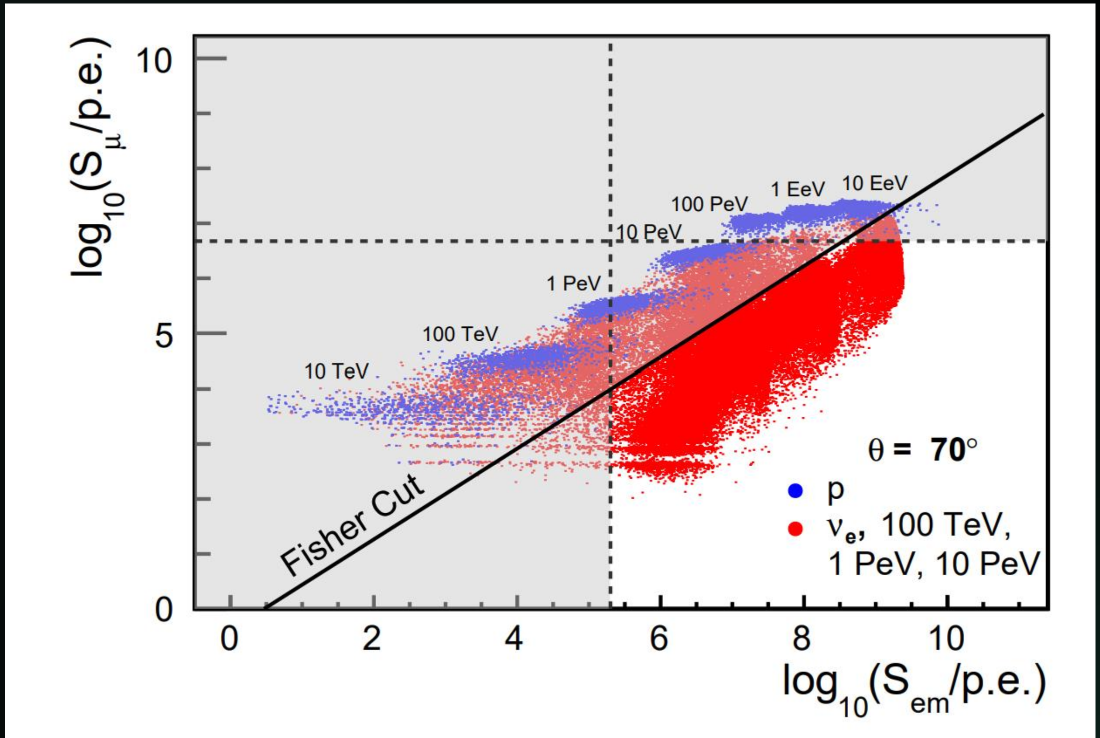
- Neutrinos typically detected using "Earth-skimming" neutrino
  - Very effective method
  - Severe limitations to sky coverage
- Recent scintillator and radio antenna upgrades
  - Direct distinction between S_{em} and S_{μ}
  - Use these variables to distinguish vertical events
  - Low acceptance issue solved

NEW STRATEGY

- Fisher discriminant to distinguish populations within $\log(S_{em})$ vs $\log(S_{\mu})$ space
- Obtain neutrino detection efficiency

Calculate differential neutrino flux:

$$E^2 \frac{dN}{dE} = E^2 \left(2\pi A \Delta E \Delta t \iint \frac{\sigma}{m} sin\theta\ cos\theta\ \varepsilon(E, D, \theta) d\theta dD \right)^{-1}$$



[1] Phys.Rev.D 106 (2022) 10, 102001

PREVIOUS RESULTS

Using a threshold (background rejection factor) of 10^{-4}:

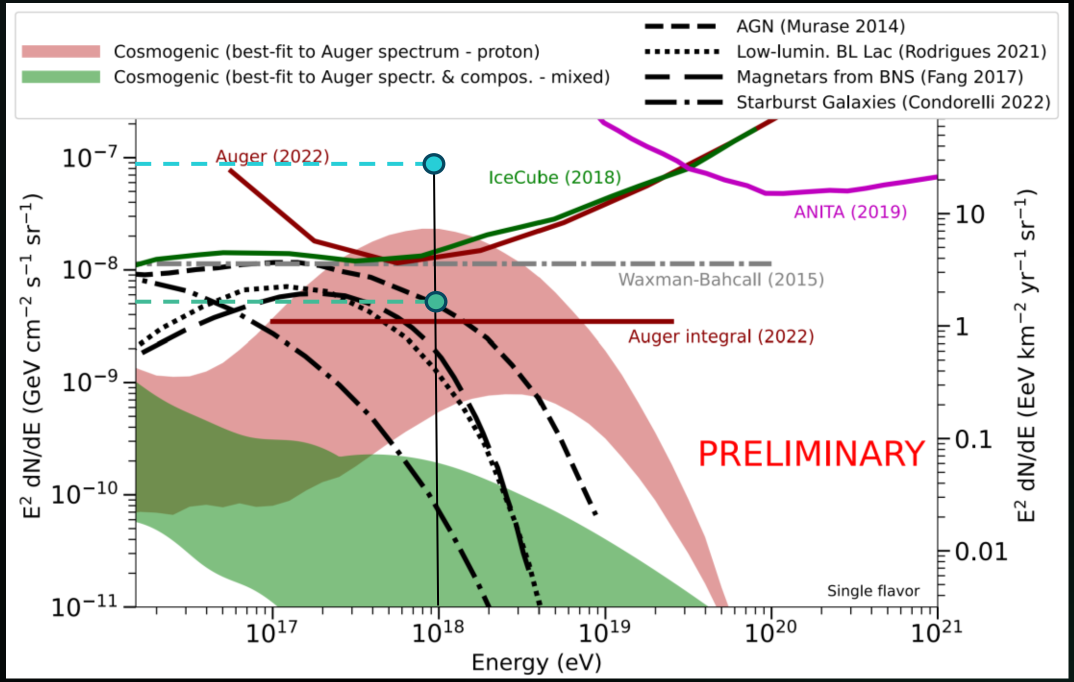
Muon neutrino:

Differential flux estimate: 8.68×10^{-8} GeV cm^{-2} s^{-1} sr^{-1}

Electron neutrino:

Differential flux estimate: 4.09×10^{-9} GeV cm^{-2} s^{-1} sr^{-1}

- While at a lower efficiency, muon neutrino can also contribute to the total neutrino flux
- Demonstrated the viability of vertical neutrino detection



Muon neutrino

Electron neutrino

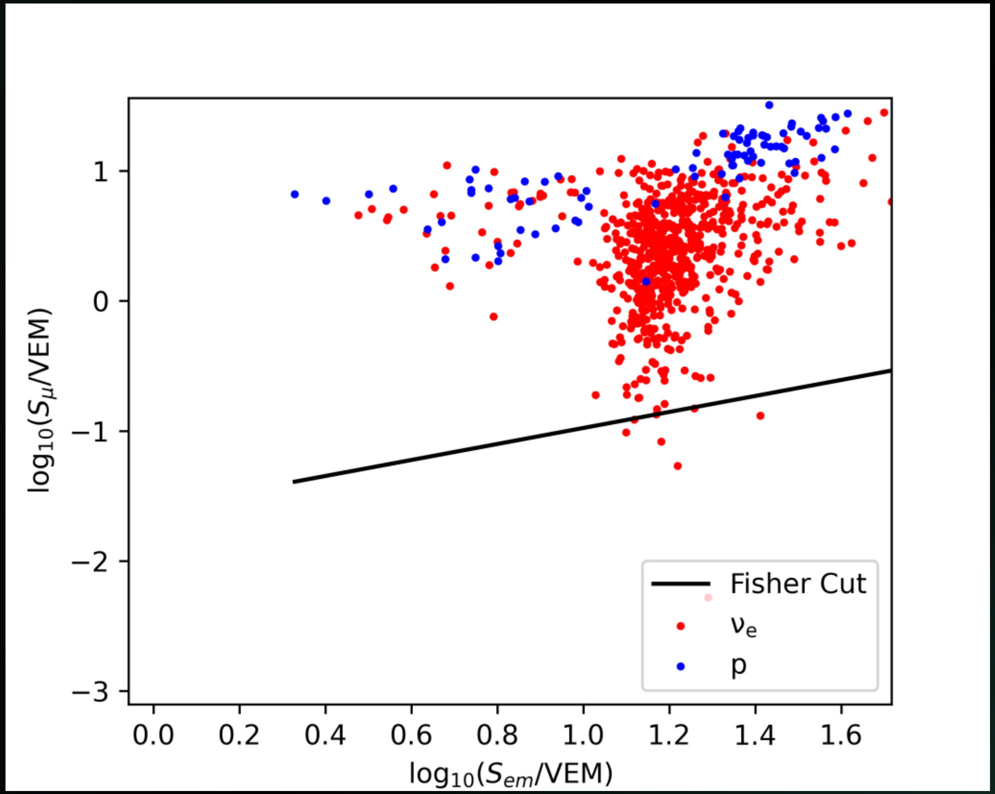
MASTER THESIS PROPOSAL

- New idea: Use X_{max} along S_{em} and S_{μ} to increase sensitivity to neutrino detection
- Use FDs to extract e.m. longitudinal profile and fit according to USP:

$$N' = \left(1 + \frac{RX'}{L}\right)^{R^{-2}} \exp\left(-\frac{X'}{LR}\right)$$

- Evident increase in neutrino-to-proton ratio for specific X_{max} bins, however for most bins (and data) the Fisher cut is inconsistent

X_{max} bin ∈ [838 , 939] g cm^{-2}



OBJECTIVES

- Switch Fisher analysis to BDT to solve statistics problem
- New radio antennas being installed for Auger Prime upgrade could replace FDs, solving low duty-cycle issue as well as increasing resolution on X_{max}
- Increase detection efficiency while expanding the coverage of the sky

THANK YOU!

David Dias

2nd Cycle Integrated Project in Engineering Physics

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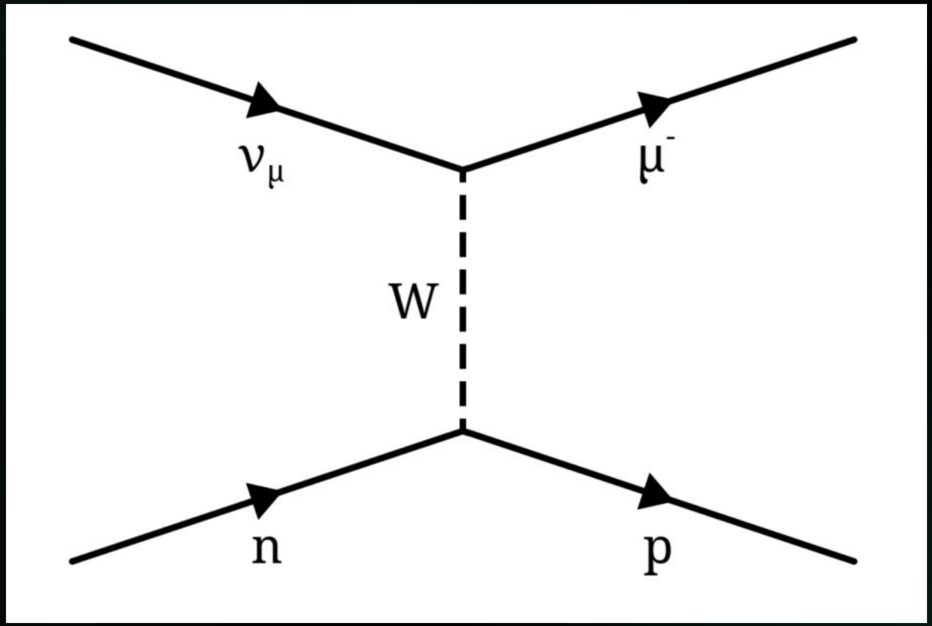
BONUS SLIDES

MUON NEUTRINO

Can we apply a similar procedure as the electron neutrino?

- Interaction with atmosphere produces high energy muon
- Above critical energy (~3 TeV) muon will radiate through bremsstrahlung
- Photon then generates electromagnetic cascade
- Atmospheric proton produces hadronic cascade



DIFFERENTIAL NEUTRINO FLUX

Expected neutrino count:

$$N = \int \Phi(E)\, \sigma(E)\, A\, \Delta t\, \varepsilon(E, D, \theta)\, sin\theta\, cos\theta\, dEd\theta dD \leq 1$$

Assume small energy interval with constant flux $\Phi = \frac{dN}{dE}$ and $\sigma(E) = \frac{\sigma}{m}$

$$N \approx \Phi(E) A\, \Delta E \Delta t \int \frac{\sigma}{m} \varepsilon(E, D, \theta)\, sin\theta\, cos\theta\, d\theta dD$$

Since no neutrinos have been detected N=1, differential neutrino flux:

$$E^2 \frac{dN}{dE} = E^2 \left(2\pi A \Delta E \Delta t \iint \frac{\sigma}{m} sin\theta\, cos\theta\, \varepsilon(E, D, \theta) d\theta dD \right)^{-1}$$